

Two-body nucleon-nucleon correlations in Glauber-like models¹

Maciej Rybczyński[†] and Wojciech Broniowski^{†,‡}

[†] *Institute of Physics, Jan Kochanowski University, PL-25406 Kielce, Poland*

[‡] *The H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, PL-31342 Kraków, Poland*

Abstract

We investigate the role of the central two-body nucleon-nucleon correlations on typical quantities observed in relativistic heavy-ion collisions. Basic correlation measures, such as the fluctuations of the participant eccentricity, initial size fluctuations, or the fluctuations of the number of sources producing particles, are sensitive at the level 10-20% to the inclusion of the two-body correlations. However, the realistic correlation function gives virtually indistinguishable results from the *hard-core repulsion* with the expulsion distance set to ~ 0.9 fm. In the second part of the talk we compare the spherical and Gaussian wounding profiles and find that the latter, which is more realistic, leads to reduced eccentricity and fluctuations. This has significance for precision studies of the elliptic flow.

Recently Refs. [1, 2] published distributions of nucleons in nuclei which account for the central Gaussian two-body nucleon-nucleon (NN) correlations, which is an important ingredient for the Glauber-model investigations [3, 4] of relativistic heavy-ion collisions. Up till recently the Glauber Monte Carlo codes [5, 6, 7, 8, 9] have not been incorporating realistic NN correlations. Instead, the easy-to-implement hard-core expulsion has been used.

The most popular model of the early stage of the collision is the *wounded-nucleon model* [13]. Variants of the approach [7, 14, 15, 16] admix a certain fraction of binary collisions to the wounded nucleons, which leads to a better overall description of multiplicities of the produced particles. In this *mixed model*, used throughout the talk, the number of the produced particles is proportional to the number of *sources*,

$$N_s = (1 - \alpha)N_w/2 + \alpha N_{\text{bin}}, \quad (1)$$

where N_w is the number of the wounded nucleons (those who interacted inelastically at least once) and N_{bin} denotes the number of binary collisions.

¹Talk presented by MR at the VI Workshop on Particle Correlations and Femtoscopy, BITP, Kiev, 14-18 September 2010.

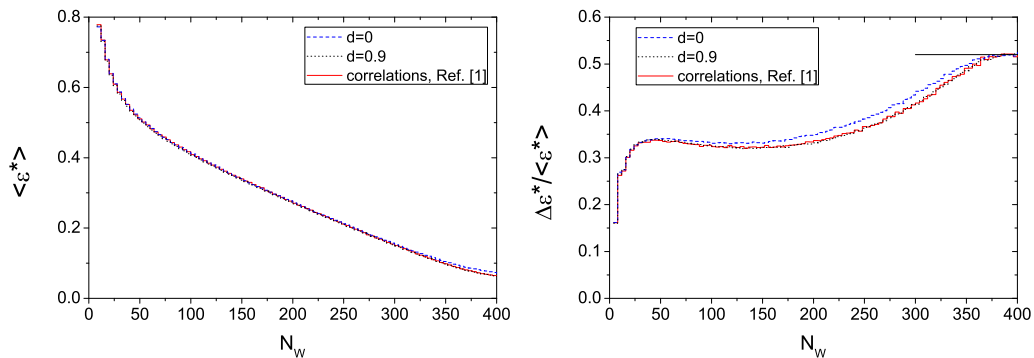


Figure 1: Left: the average participant eccentricity, $\langle \varepsilon^* \rangle$, plotted vs the number of wounded nucleons, N_w , obtained with the three investigated nucleon distributions described in the text. Right: The scaled standard deviation, $\Delta \varepsilon^* / \langle \varepsilon^* \rangle$, obtained from an event-by-event study. The short horizontal line at the most central events corresponds to the value $\sqrt{4/\pi - 1}$ of Ref. [22] following from the central limit theorem. $^{208}\text{Pb} - ^{208}\text{Pb}$ collisions.

sions. More sophisticated approaches [17] discriminate between the nucleons which have collided only once (corona) and more than once (core). Also, the wounded-quark model [18, 19, 20] yields a quite successful phenomenology. In this talk we apply the mixed model for the $^{208}\text{Pb} - ^{208}\text{Pb}$ collisions with $\alpha = 0.12$, corresponding to the highest SPS energy.

First, we compare the results of the Glauber calculation initialized with the correlated distributions of Ref. [1, 2] (solid lines in the figures), with uncorrelated distributions (dashed lines), and with the distributions accounting for the hard-core repulsion with the expulsion radius $d = 0.9$ fm (dotted lines). The Monte Carlo simulations are performed with GLISSANDO [7]. We start with the *participant* eccentricity, ε^* , appearing in the studies of the event-by-event fluctuations of the initial shape, in particular of its elliptic component [10, 11]. In the left panel of Fig. 1 we show the dependence of the event-by-event average, $\langle \varepsilon^* \rangle$, on N_w . We note that the three calculations are virtually indistinguishable, except for a tiny difference for the most central collisions, where the uncorrelated case is a few percent higher. The same conclusions were reached in the analogous study of eccentricity in Ref. [21].

The right panel of Fig. 1 shows the scaled standard deviation of the participant eccentricity, $\Delta \varepsilon^* / \langle \varepsilon^* \rangle$, obtained from our event-by-event analysis. We note a significant difference between the uncorrelated case, which has up

to 10% larger fluctuations at intermediate centralities, and the cases with correlations. However, the calculations with the realistic NN correlations and the hard-core correlations give a virtually indistinguishable result, with the two curves overlapping within the statistical noise. The short horizontal line at the most central events corresponds to the value $\sqrt{4/\pi - 1}$ of Ref. [22], following from the central limit theorem for the most central events.

Now we pass to the second part of the talk. In the existing Glauber Monte-Carlo codes there is a common use of the spherical wounding profiles. In other words, the collision occurs when the transverse distance between the centers of the colliding nucleons, b , is less than R , where, geometrically, $\pi R^2 = \sigma_{inel}$. We can also write that the collision probability distribution in b (the wounding profile) has the form $\sigma(b) = \Theta(R - b)$. However, it was shown in Ref. [12] that the use of the wounding profile in the Gaussian form,

$$\sigma(b) = A \exp\left(\frac{-Ab^2}{R^2}\right), \quad (2)$$

with $A = 0.92$ tuned to the NN scattering data, leads to much more realistic results. In particular, a combination of gaussians can explain in detail the nucleon-nucleon elastic cross section, including its diffractive features. Although the integrated NN cross section is by construction the same for the Gaussian and the hard-sphere wounding profiles, $\int d^2b \sigma(b) = \pi R^2$, the Gaussian profile has a tail, making a collision of distant nucleons possible.

We have investigated the influence of the Gaussian wounding profile on the participant eccentricity and on the scaled variance of the number of sources, ω_s , defined as

$$\omega_s = \frac{\text{Var}(N_S)}{\langle N_S \rangle}. \quad (3)$$

In the left panel of the Fig. 2 we have plotted the average participant eccentricity, $\langle \varepsilon^* \rangle$, vs the number of wounded nucleons, N_w , obtained with the correlated [1] nucleon distribution for the spherical and Gaussian wounding profiles. There is a visible 10 – 15% quenching of $\langle \varepsilon^* \rangle$ seen in peripheral collisions for the Gaussian wounding profile in comparison to the spherical profile. The simple explanation of the fact is that with more extended wounding profile the in-plane nucleons have a larger chance to become wounded, which decreases $\langle \varepsilon^* \rangle$. This quenching, although not very large, has significance for precision studies of the elliptic-flow coefficient, v_2 , which in hydrodynamic

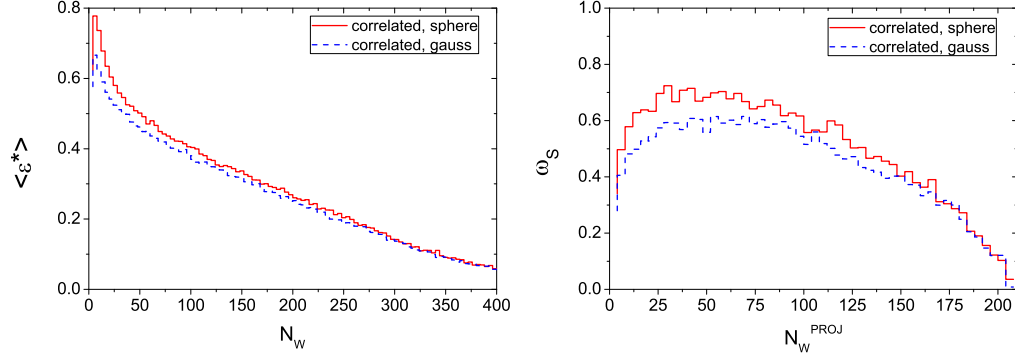


Figure 2: Left: the average participant eccentricity, $\langle \varepsilon^* \rangle$, plotted vs the number of wounded nucleons, N_w , obtained with the correlated [1] nucleon distribution for the spherical and Gaussian wounding profiles (see the text for details). Right: The scaled variance of the number of sources, ω_S , plotted as a function of the number of wounded nucleons in the projectile, N_w^{PROJ} , for the case two wounding profiles.

studies is sensitive to the initial eccentricity. While taking into account the fluctuations (participant eccentricity) increases $\langle \varepsilon^* \rangle$, the use of the realistic wounding profile brings it down.

The right panel of the Fig. 2 shows the scaled variance of the number of sources, ω_S , plotted as a function of the number of wounded nucleons in the projectile, N_w^{PROJ} . Here we also note a decrease of the fluctuations when the Gaussian wounding profile is used.

The current version of the GLISSANDO package can be downloaded from <http://www.ujk.edu.pl/homepages/mryb/GLISSANDO/index.html>.

Research supported by Polish Ministry of Science and Higher Education, grants N N202 263438 and N N202 249235.

References

- [1] *Alvioli M., Drescher H. J., and Strikman M.*
Phys. Lett. B. 2009. V.680. P.225.
- [2] *Alvioli M., Drescher H. J., and Strikman M.*
2009. <http://www.phys.psu.edu/~malvioli/eventgenerator/>
- [3] *Glauber R. J.*
Lectures in Theoretical Physics, New York: Interscience, 1959.
- [4] *Czyż W. and Maximon L. C.*
Annals Phys. 1969. V.52. P.59.
- [5] *Wang X.-N. and Gyulassy M.*
Phys. Rev. D. 1991. V.44. P.3501.
- [6] *Werner K.*
Phys. Lett. B. 1988. V.208. P.520.
- [7] *Broniowski W., Rybczyński M., and Bożek P.*
Comput. Phys. Commun. 2009. V.180. P.69.
- [8] *Alver B., Baker M., Loizides C., and Steinberg P.*
2008. arXiv:0805.4411.
- [9] *Miller M. L, Reygers K., Sanders S. J. , and Steinberg P.*
Ann. Rev. Nucl. Part. Sci. 2007. V.57 P.205.
- [10] *Bhalerao R. S., Blaizot J.-P., Borghini N., and Ollitrault J.-Y.*
Phys. Lett. B. 2005. V.627. P.49.
- [11] *Andrade R., Grassi F., Hama Y., Kodama T., and Socolowski J.*
Phys. Rev. Lett. 2006. V.97. P.202302.
- [12] *Bialas A., Bleszynski M., and Czyż W.*
Acta. Phys. Pol. B. 2007. V.38. P.159.
- [13] *Bialas A. and Bzdak A.*
Nucl. Phys. B. 1976. V.111. P.461
- [14] *Kharzeev D. and Nardi M.*
Phys. Lett. B. 2001. V.507. P.121

- [15] *Back B. B. et al. (PHOBOS Collaboration)*
Phys. Rev. C. 2002. V.65. P.031901.
- [16] *Back B. B. et al. (PHOBOS Collaboration)*
Phys. Rev. C. 2004. V.70. P.021902.
- [17] *Bożek, P.*
Acta. Phys. Pol. B. 2005. V.36. P.3071.
- [18] *Bialas A, Czyż W., and Furmanski W.*
Acta. Phys. Pol. B. 1977. V.8. P.585.
- [19] *Bialas A, Czyż W., and Lesniak L.*
Phys. Rev. D. 1982. V.25. P.2328.
- [20] *Bzdak A.*
Acta. Phys. Pol. B. 2008. V.39. P.1977.
- [21] *Tavares B. M., Drescher H. J., and Kodama T.*
Braz. J. Phys. 2007. V.37. P.41.
- [22] *Broniowski W., Bożek P., and Rybczyński M.*
Phys. Rev. C. 2007. V.76. P.054905.